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AUDITORY BINAURAL BEATS ENHANCE EEG-MEASURED BETA WAVE ACTIVITY IN INDIVIDUALS WITH ADHD

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Introduction

In January of 2002, a consortium including the U.S. surgeon general, the American Medical Association, the American Psychiatric Association, the American Psychological Association, and the American Academy of Pediatrics issued an International Consensus Statement on ADHD, confirming their collective recognition of ADHD as a legitimate disorder. Their statement attested to several points: first, that ADHD involves a serious deficiency in psychological abilities; second, that deficits in behavioral inhibition and sustained attention are central to this disorder; and third, that for those it afflicts, ADHD can cause devastating problems.

ADHD affects 7-10 percent of all school-age children, or about three million children in the United States. The behavioral symptoms of ADHD are usually evident between the ages of three and five. Until recently, boys were thought to be at least three times more likely than girls to develop the disorder. In a longitudinal study performed during the 1990s on boy-to-girl ADHD ratios among health maintenance organization (HMO) youth, however, there was a marked change in the gender disparity. In 1991, the male to female ratio was 9.8 to 1 versus the 1999 ratio of 4.6 to 1, indicating that girls were diagnosed in increasing numbers during the 1990s. Current studies also show that as many as 67 percent of children diagnosed with ADHD will continue to experience symptoms serious enough to interfere with academic, vocational, and social functioning as adults.

Current treatment includes medication and psychological counseling. Medication remains the backbone of treatment protocols due to its confirmed short-term benefits. Stimulants increase activity in parts of the brain that are underactive in ADHD individuals. Experts believe that this increase in neural activity improves attention and reduces impulsive, hyperactive, or

aggressive behavior. These drugs increase the functional bioavailability of dopamine and therefore increase the probability that dopamine will bind to its receptors on other neurons, but medication alone has not been shown to improve the long-term outcome of ADHD. Furthermore, the most frequently prescribed medications (methylphenidate, atomoxetine, dextroamphetamine, etc.) generally result in side effects that include decreased appetite, stomachaches, difficulty falling asleep, and mood swings. New methods for improving attentional functions within this population need to be investigated.

What is Paying Attention?

Attention is functionally defined as the cognitive process combining concentration, mental focus, engrossment, and interest. Attention can engage several neural structures at the same time. It sometimes involves searching for something stored in long-term memory, while holding information in working memory, along with ignoring irrelevant information. The inability to manage these attentional functions is particularly problematic in a classroom setting.

Current Search for a Cause-Electroencephalography

Ninety-seven percent of the activity that occurs in the brain is integrated at the cortical level. Electrical changes in the brain's cellular membrane polarization and inhibitory and excitatory potentials result in voltage that is carried throughout the brain. The voltage travels toward the cortex and may be measured from the scalp as microvolts. Electroencephalographic (EEG) measures of brain activity indicate that individuals with ADHD have difficulty maintaining the high levels of cortical arousal associated with sustained alertness and focused attention. Specifically, they show an insufficient amount of coordinated hemispheric brain-wave patterns, especially within the beta frequency range.

There are four levels of electrical signals present in our brain: the 12-24 Hz beta waves, which are dominant when we are alert; the 7-11 Hz alpha waves, which are created when we are more relaxed; the 4-6 Hz theta waves that occur when we are daydreaming; and the less than 4 Hz delta waves present while we are sleeping. For individuals with ADHD, it is likely that what we need is a method by which to bring the deficient level of beta brain waves into the normal frequency range.

Music and the Brain

For those with ADHD, brain waves in several frequency ranges may be abnormal. A deficiency in the delta and theta ranges adversely affects sleep patterns and creativity. Other studies show clearly that below-normal beta frequency brain waves interfere with maintaining attention. In an effort to raise deficient brain waves to a more normal level, researchers have looked to other disciplines for answers. Neurologist Oliver Sacks[1] has noted a particularly interesting effect. In 2000, Dr. Sacks discovered that by merely listening to classical music, his

stroke and Alzheimer's patients briefly came alive after being literally frozen by the effects of their disease. For reasons we do not yet understand, patients who are unable to use words in speech are still able to sing those words. EEGs of his patients' brains during this transformation showed that their brain waves picked up speed and showed a much more normal waveform while listening to classical music.

Further studies show that it is actually certain beats within classical music that affect brain waves. Sornson's research[2] has shown that beta-harmonic sound patterns, specially designed to increase the level of beta brain-wave activity, enhance the absolute power of waveforms as measured objectively between baseline control conditions and experimental binaural-beat conditions. In a study of forty-one elementary school children with ADHD, 30 percent demonstrated significant improvement in behavior and achievement when music containing binaural beats was played in the classroom. An improvement in mood for college students was demonstrated in a study during which "binaural beat auditory stimulation significantly influenced affective processes even when people were unaware that such signals were being presented." It seems that music containing binaural harmonic frequencies may help synchronize brain activity and result in improved ability to maintain attention.

Binaural Beats and How They Work

When tones of two different frequencies are presented separately to each ear, the superior olivary nuclei within the medulla of the brain stem synthesize the two sounds into a single low-frequency tone, the binaural beat. The binaural beat pulses with the overall frequency of the difference between the two original tones. This electrical activity is then conducted to the cortex where it may be recorded by EEG electrodes and displayed as waveforms showing the electrical activity in the form of amplitude of voltage spread over time. If the difference between tones matches a particular brain-wave state, such as the 4-6 Hz theta range, the 7-11 Hz alpha range, or the 12-24 Hz beta range, then the overall brain activity will maintain that brain-wave state. Research suggests that auditory binaural beats within specific electroencephalograph frequency ranges can enhance corresponding brain-wave activity and may affect levels of cognition.

Finally, we must consider the pathways within the brain that transmit the binaural beats to the cortex for processing. The reticular activating system (RAS), a large net-like region in the brain stem, plays a major role in filtering sensory input and focusing attention and awareness and is strongly involved in the cortical processing of binaural beats. Studies indicate that the binaural signals are processed in the RAS.

Since many researchers believe that different brain waves correspond to the production of specific neurochemicals in the brain, the positive effect of auditory binaural beats at the neurological level may be twofold. Bauer[3] described how this process occurs: "What I believe

is happening … is that by sending out the proper frequency, waveform, and current… we change the configuration of the cell membrane. Cells that are at suboptimal levels are stimulated to 'turn on' and produce what they are supposed to produce, through DNA, which is stimulated through the cell membrane. You are charging the cells through a biochemical process that can possibly balance the acetylcholine or other neurotransmitters that need to be turned on." Several studies in neurology suggest that a primary function of the RAS is to adjust levels of the neurotransmitter acetylcholine and that this activity manages cortical-arousal states. Acetylcholine has also been associated with higher intelligence-test scores, which coincide with one's ability to maintain attention.

Focus of This Study

This research tested whether auditory binaural-beat stimulation would result in enhanced EEG-measured beta brain-wave activity in individuals with ADHD. The internal communication system of the brain is based on frequency of neural impulses. Influencing the frequency of beta brain-wave activity should improve the cognitive focus of people with ADHD.

Methods

Participants

Eleven individuals with ADHD, aged six to forty-three years, were recruited from a local Center for Children with Attentional Disorders counseling facility, from local chapters of the nationwide ADHD support group CHADD (Children and Adults with Attention-Deficit/Hyperactivity Disorder), and from the California State University, Northridge (CSUN) Disability Resource Center. The participants in this study were diagnosed as having ADHD (five had been diagnosed by medical doctors and six had been diagnosed by psychologists) and were taking medication for their condition. Based on findings that medications prescribed for ADHD do not produce a clear change in EEG measures, the participants in this study remained on their prescribed regimen. These participants had no hearing impairment and were free from past closed-head injury and seizure disorder. Anyone with a hearing impairment was also screened out. All eleven of the recruits completed the study. The group was comprised of seven males, three of them children; and four females, one a child. Culturally, two participants were Asian, one was Filipino, three were Middle Easterners, and five were Caucasian.

Materials

Binaural-Beat Stimulation

Two compact discs (CDs), each entitled *Einstein's Dream*, were specially produced for this project by The Monroe Institute. The control-phase CD contained no binaural-beat stimulation, and the CD for the experimental phase did. The beta tones were presented with 16 and 24 Hz

binaural beats. Subjectively, the two CDs sounded identical and were presented to the participants through battery-operated stereo headphones.

Attentional Task

A modified version of the Conners' Continuous Performance Test 3.0 (CPT) was used during each "music" phase as a behavioral assessment of improvement in task completion while listening to music containing binaural beats. The attentiveness scores for this behavioral task were analyzed by the program and included measures for correct responses measuring sustained attention (pressing the mouse button each time any letter but an "X" appeared on the screen), errors of omission measuring selective attention (not pressing the mouse button when required), and errors of commission measuring impulse control (pressing the mouse button when not required).

During an initial practice phase, each participant was seated in a clinical counseling chair with the mouse on a shelf in front of him or her. The CPT was presented on a high-resolution seventeen-inch computer monitor and was programmed to administer a four-minute segment of stimuli per phase. Stimuli letters of the alphabet were shown, and the person practiced clicking the mouse each time any letter but an "X" appeared on the screen.

Electroencephalography

EEG recording was accomplished using a BIOPAC Systems, Inc., Data Acquisition Unit, along with electrode lead sets, disposable vinyl electrodes, electrode gel, adhesive electrode holders, and abrading paste. This system uses a noninvasive method of recording bioelectric activity of the brain at the scalp. The BIOPAC equipment is widely used in research laboratories to acquire measures of instantaneous activity within the cerebral hemispheres at the cortical level. EEG translates electrical activity from neurons, and during this study the electrical activity was collected through a monopolar electrode placed at the International 10-20 System of Electrode Placement scalp location of Cz with electrodes attached to each earlobe, one acting as a reference and the other as a ground. Impedance levels were checked for each electrode and were kept below 10 kilo-ohms. The key EEG power that correlates with most cognitive tasks is the 12-24 Hz beta frequency band, whose power is "maximal at the central electrode sites." The theta/beta ratio recorded at the Cz electrode placement has been shown to be 93 percent accurate for predicting ADHD in children. BIOPAC AcqKnowledge® software was used to record the EEG data, filter the data into the specific bandwidths for alpha, theta, beta, and delta, and display the results on-screen in real time. The software includes procedures for analyzing EEG signals and quantifying the relative and total power in each band. Additionally, the fluorescent lights in the laboratory were turned off during all EEG recording phases to avoid the 60 Hz spikes they cause during recording. Only illumination from the incandescent ceiling fixtures was utilized.

Procedure

This study was conducted at CSUN's Computerized Attention and Speech Center for Individuals with ADHD laboratory. Children were accompanied by at least one parent at all times while on campus.

After the consent and screening forms were completed, the participant was familiarized with the CPT program. Each person practiced the CPT for three to five minutes until he/she was comfortable with the protocol required to respond to the appearance of letters on the monitor.

Participants (and their parents, in the case of child participants) were kept blind to the true purpose of the project. When recruited, they were told that the project was being undertaken to rate a new computerized attentional task designed for individuals with ADHD and that the consistency of their scores across two different sections of the task would be measured. During each session, participants were told that the CDs they were listening to were meant to block out any distracting external noise. The deception was essential to prevent any expectation bias, and participants (and their parents) were debriefed and thanked at the conclusion of their session.

After the child participants had been familiarized with the CPT, they chose a new small toy from the researcher's toy chest, which they were allowed to keep. The toy was placed on the floor in front of the child to facilitate his/her fixating on one visual point (looking down eliminates many artifacts of muscle movement). The adult participants were asked to pick and concentrate on a focal point on the floor.

The EEG electrodes were fitted to each participant according to the international 10-20 electrode-placement system. Five EEG recording phases were designed for this project (see Figure 1). During the first two-minute baseline-recording phase, each person was asked to look down at the floor, focus his/her eyes on the small toy or focal point, remain as still as possible, and refrain from blinking. During the second recording phase, stereo headphones (powered by batteries) were placed over the participant's ears and he/she listened to a CD playing soft music containing no binaural beats (while continuing to focus his/her eyes on the small toy or the focal point). Two more minutes of EEG were recorded. Third, while still listening to non-binaural-beat music, the person completed four minutes of the CPT. Fourth, the participant listened to a CD playing soft music containing binaural beats, and the next two minutes of EEG activity were recorded. Two minutes of recording was considered adequate since the onset of binaural beat oscillation is immediate. Finally, while still listening to the music containing binaural beats, the person completed four more minutes of the CPT.

Project protocol included EEG recording during all five phases of the experiment. As expected, the Phase I baseline recording appeared to be very similar to the Phase II (non-binaural-beat music) recording, and Phase III and Phase V (during which the participant worked on the CPT)

were not analyzed since they were comprised mainly of movement artifacts. The protocol design was successful, however, since the fact of the two “music” recordings being the focal phases was concealed from the participant. After each phase of EEG recording, the children placed a sticker next to that phase number on a one-page checklist, personalized for each child. Since the frequency effects of binaural beats have been found to last from twenty minutes to one hour or more, any influence of order effect in this study was sacrificed to avoid carryover effects.

Figure 1: Five Experimental Phases

- Phase I Two-minute baseline recording
- Phase II Two-minute non-binaural-beat recording
- Phase III Four minutes of CPT while still listening to non-binaural-beat music
- Phase IV Two-minute binaural-beat recording
- Phase V Four minutes of CPT while still listening to binaural-beat music

Results

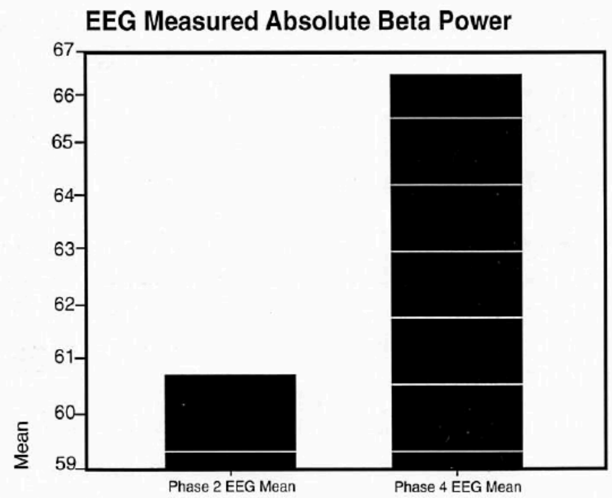
Electroencephalography

The EEG software package utilized in this study provided a composite of spectral outputs by which to observe recorded brain waves. All wave-recorded formats were downloaded into files that were opened and analyzed in the computer program SPSS.

The analog EEG waves (amplitude measured as voltage over time) were sampled at a rate of 200 samples per second and were translated by the software into digital values accounting for the voltage of each three-second epoch. Fast Fourier transformation was used to process the voltage over time into voltage over frequency to display the level of electrical energy (power) of the beta, and mean power was calculated for each epoch.

A paired-samples t test analysis was used to compare any change in power between Phase II and Phase IV. Absolute beta frequency power was found to be significantly higher during Phase IV, recorded while participants were listening to music containing binaural beats ($M = 66.544$), than during the non-binaural-beat music presented during Phase II ($M = 60.670$), $t(10) = -8.362$, $p < .001$.

Figure 2: SPSS Bar Chart of Beta Brain-Wave Activity

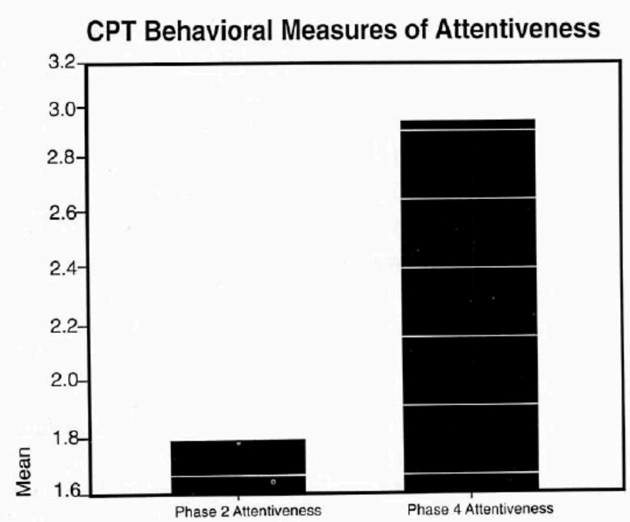


Attentional Performance

The CPT was scored using the program's attentiveness analysis for the task completed during each phase. In accordance with signal detection theory, the attentiveness score was analyzed by calculation of d´. The sensitivity measure of d´ is the distance along the X-axis between the noise distribution and the signal distribution in standard-score units.

A paired-samples t test was used again to maximize statistical power in comparing the attentiveness scores during Phase II and Phase IV. Participants exhibited a significantly higher attentiveness level during the binaural-beat phase ($M = 2.946$) than during the non-binaural-beat phase ($M = 1.783$), $t(10) = -5.773$, $p < .001$.

Figure 3: SPSS Bar Chart of CPT Attentiveness Measure



Discussion

Support of Previous Studies

It is expected that the improvements in attention found in this study were a result of improved levels of electrical arousal within the brain elicited by the auditory binaural beats. The observed effects were consistent with the hypothesis regarding the enhancing effects of binaural beats in the beta frequency range on absolute power of beta brain waves as measured in individuals with ADHD. Binaural beats in the EEG beta frequency range were associated with significantly higher levels of attentiveness during the binaural-beat condition compared to attentiveness results during the non-binaural-beat condition. These findings lend empirical support to studies showing that auditory binaural beats have a positive effect on vigilance, on memory, and on other measures of attention.

The attentional improvement was recorded in the absence of participant or parental expectations, and precise experimental design ruled out other confounding effects. All listening phases of this study maintained the explanation that headphones and music were utilized to eliminate external auditory distractions, and the CDs were placed in the player out of the participant's view so that they would remain unaware that different treatments were being presented.

It is expected that the improvements in the attentional task were influenced by changes in the levels of absolute beta frequency electrical activity resultant from binaural-beat stimulation. Moreover, it would normally be expected that scores on the final CPT measure would be considerably lower due to performance decline as a result of working with the same boring task for the third time. According to Conners,[4] "In a boring task children become less efficient as they become less strict in deciding whether a signal is a target or not." The results of this study showed a significant increase in CPT attentiveness scores for the final phase and suggest support of the positive effect of the binaural-beat recording. This explanation coincides with prior studies that support the finding of changes in EEG in response to presentation of binaural beats. The evidence of improvement in beta-wave activity when presented with binaural beats deserves further study using brain-wave-measuring tools that allow for quantitative analysis of any normalization of waveform.

In addition to Lane et al.'s [5] finding a significant improvement for subjects as measured using a continuous performance task programmed specifically for their project, this study provides supportive evidence that performance on attentional tasks is significantly improved when individuals are listening to music containing binaural beats in the beta frequency range. In tests involving the effect of binaural beats on memory, Kennerly's results[6] indicated that beta frequency binaural-beat audio signals were a successful method for "facilitating simple free recall memory, ability to attend, and the ability to persevere at routine motor tasks." As Lubar

et al.[7] have shown, enhanced beta activity resulted in significant improvement on the Test of Variables of Attention (TOVA) in three different studies of children with ADHD. Overall, the findings in this study corroborate and extend previous research, indicating that listening to music containing binaural beats in the beta frequency range enhances beta brain-wave activity and increases performance on attentional tasks for individuals with ADHD.

Future Directions

Future studies should be organized for children with ADHD within their school setting. Given the significant improvement in beta brain-wave functioning, it is recommended that a study be designed in which students with ADHD would listen to beta frequency binaural-beat music between their classes. Since the onset of binaural beats is immediate and the effects last up to one hour or more, we may see an improvement in classroom attention and comprehension for this population.

Although beyond the scope of this study, future research should analyze the correlation between the production of different neurotransmitters and beta waves in the ADHD brain. According to Patterson et al.,[8] each brain area generates impulses at a specific frequency, based on the predominant neurotransmitters it secretes. For example, a 10 Hz signal boosts production and turnover rate of serotonin (as cited in Burgio).[9] The implications of this research are that by modifying brain-wave frequencies, it may be possible to alter the brain's neurochemistry and functioning. This suggests further research into the possibility of ameliorating depression and other disorders that are related to low serotonin levels, along with other types of deficits in cognitive functioning, by triggering the release of beneficial neurotransmitters. By engaging in a variety of disruptive behaviors in school and group settings, children with ADHD frequently experience peer rejection and usually live with increased levels of parental and sibling conflicts. The positive benefits from auditory binaural beats may permeate both the behavioral and emotional symptoms of the disorder--functionally improving each and also improving interactions between the two.

Due to the short-lived normalization effects of current medication treatments for ADHD, we need to study the extent to which the attentional improvement experienced by these participants after being presented with binaural beats is sustained after auditory stimuli is withdrawn. If the effect of binaural beats is prolonged, we may be able to find a way in which individuals could self-stimulate their beta frequency brain waves when inattentive states occur throughout the day. Binaural-beat brain-wave enhancement could offer a cost-effective, nonmedication alternative to families and school systems seeking to supplement standard treatment protocol. Since there is no cure for ADHD, it is important to develop multimodal treatment plans combining medication, behavioral therapy, and, potentially, scheduled exposure to beta frequency binaural beats.

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